

1 1. A method of characterizing a color imaging
2 system, the method comprising:
3 obtaining first data indicative of output of the
4 color imaging system;
5 processing the first data, to yield second data,
6 according to a color appearance model that varies in
7 accordance with neutrality of colors indicated by the first
8 data.

1 2. The method of claim 1 wherein the color
2 appearance model varies according to a white reference
3 vector that is a weighted combination of a local white point
4 of the color imaging system and a common white point, the
5 white reference vector being weighted more to the local
6 white point the more a color indicated by the first data is
7 neutral and being weighted more to the common white point
8 the more the indicated color is saturated.

1 3. The method of claim 2 wherein the color imaging
2 system is an emissive system and processing the first data
3 includes using a media white point as the local white point
4 to implement absolute colorimetry.

1 4. The method of claim 1 wherein the color
2 appearance model varies as a function of intensity of the
3 color indicated by the first data.

1 5. The method of claim 4 wherein the color
2 appearance model includes a luminance descriptor, and a pair
3 of color descriptors that quantify relative amounts of red,
4 green, yellow, and blue in a color indicated by the second
5 data;

6 wherein the luminance descriptor varies as a
 7 function of Y, Y being one of tristimulus values X, Y, and Z
 8 of the color indicated by the first data; and
 9 wherein the pair of color descriptors vary as
 10 functions of the neutrality of the color indicated by the
 11 first data.

1 6. The method of claim 5 wherein the luminance
 2 descriptor varies as a function of a Y-reference that is a
 3 weighted combination of a local white point Y-value and a
 4 common white point Y-value, the Y-reference being weighted
 5 more toward the local white point Y-value the closer the Y-
 6 value of the color indicated by the first data is to the
 7 local white point Y-value and being weighted more toward the
 8 common white point Y-value the more the Y-value of the color
 9 indicated by the first data and the local white point Y-
 10 value differ.

1 7. The method of claim 6 wherein the second data
 2 include values for L^* , a^* , and b^* ; and
 3 wherein
 4 $L^* = 116 \times f(Y/Y_n) - 16$
 5 $Y_n = Y_{LW}(1 - \text{sat}(Y, Y_{LW})) + Y_{CW} * \text{sat}(Y, Y_{LW})$
 6 $\text{sat}(Y, Y_{LW}) = 1.0 - (Y/Y_{LW})$
 7 $a^* = 500(f(X/X_n') - f(Y/Y_n'))$
 8 $b^* = 200(f(Y/Y_n') - f(Z/Z_n'))$
 9 $f(\omega) = (\omega)^{1/3} \quad \omega > 0.008856$
 10 $f(\omega) = 7.787(\omega) + 16/116 \quad \omega \leq 0.008856$
 11 $X_n' = X_{LW}(1 - \text{sat}(C, C_{LW})) + X_{CW} * \text{sat}(C, C_{LW})$
 12 $Y_n' = Y_{LW}(1 - \text{sat}(C, C_{LW})) + Y_{CW} * \text{sat}(C, C_{LW})$
 13 $Z_n' = Z_{LW}(1 - \text{sat}(C, C_{LW})) + Z_{CW} * \text{sat}(C, C_{LW})$
 14 $C = (X, Y, Z)$
 15 $C_{LW} = (X_{LW}, Y_{LW}, Z_{LW})$

16 $\text{sat}(C, C_{LW}) = (\text{dev}X'Y'Z' / \text{maxDev})^\gamma$
 17 $\text{maxDev} = \sqrt{6.0/9.0} * \max(X', Y', Z')$
 18 $\text{dev}X'Y'Z' = \sqrt{(\langle X' - \text{avg}X'Y'Z' \rangle)^2 + (\langle Y' - \text{avg}X'Y'Z' \rangle)^2}$
 19 $\quad + (\langle Z' - \text{avg}X'Y'Z' \rangle)^2}$
 20 $\text{avg}X'Y'Z' = (X' + Y' + Z')/3.0$
 21 $X' = X/X_{LW}$
 22 $Y' = Y/Y_{LW}$
 23 $Z' = Z/Z_{LW}$
 24 where C_{LW} is a local white vector representing a local white
 25 point of the system, $C_{CW} = (X_{CW}, Y_{CW}, Z_{CW})$ is a common white vector
 26 for a common white point of the system, and γ is a variable
 27 for scaling the local white vector C_{LW} relative to the
 28 common white vector C_{CW} .

1 8. The method of claim 5 wherein the second data
 2 include values for L^* , a^* , and b^* ;
 3 wherein L^* is closer to a relative colorimetric
 4 value of L^* than an absolute colorimetric value of L^* the
 5 closer the value of Y is to a local white point value Y_{LW} ;
 6 and
 7 wherein a^* and b^* are closer to relative colorimetric
 8 values of a^* and b^* , respectively, than to absolute
 9 colorimetric values of a^* and b^* , respectively, the closer
 10 the indicated color is to neutral.

1 9. The method of claim 8 wherein
 2 $L^* = (1.0 - \text{sat}_{L^*}) * L^*_{\text{rel}} + \text{sat}_{L^*} * L^*_{\text{abs}}$;
 3 $a^* = (1.0 - \text{sat}_{a^*b^*}) * a^*_{\text{rel}} + \text{sat}_{a^*b^*} * a^*_{\text{abs}}$;
 4 $b^* = (1.0 - \text{sat}_{a^*b^*}) * b^*_{\text{rel}} + \text{sat}_{a^*b^*} * b^*_{\text{abs}}$;
 5 $\text{sat}_{L^*} = 1.0 - (Y/Y_{LW})$;
 6 $\text{sat}_{a^*b^*} = (\sqrt{a^{*2} + b^{*2}})/L^*$; and
 7 wherein L^*_{rel} , a^*_{rel} , and b^*_{rel} are values of L^* , a^* ,
 8 and b^* , respectively, using relative colorimetry, and L^*_{abs} ,

9 a^*_{abs} , and b^*_{abs} are values of L^* , a^* , and b^* , respectively,
10 using absolute colorimetry.

1 10. A computer program product residing on a
2 computer readable medium, for characterizing a color imaging
3 system, comprising instructions for causing a computer to:
4 obtain first data indicative of output of the color
5 imaging system;
6 process the first data, to yield second data,
7 according to a color appearance model that varies in
8 accordance with neutrality of a color indicated by the first
9 data.

1 11. The computer program product of claim 10
2 wherein the color appearance model varies according to a
3 white reference vector that is a weighted combination of a
4 local white point of the color imaging system and a common
5 white point, the white reference vector being weighted more
6 to the local white point the more a color indicated by the
7 first data is neutral and being weighted more to the common
8 white point the more the indicated color is saturated.

1 12. The computer program product of claim 11
2 wherein the color imaging system is an emissive system and
3 the instructions for causing the computer to process the
4 first data cause the computer to use a media white point as
5 the local white point to implement absolute colorimetry.

1 13. The computer program product of claim 10
2 wherein the color appearance model varies as a function of
3 intensity of the color indicated by the first data.

1 14. The computer program product of claim 13
 2 wherein the color appearance model includes a luminance
 3 descriptor, and a pair of color descriptors that quantify
 4 relative amounts of red, green, yellow, and blue in a color
 5 indicated by the second data;
 6 wherein the luminance descriptor varies as a
 7 function of Y, Y being one of tristimulus values X, Y, and Z
 8 of the color indicated by the first data; and
 9 wherein the pair of color descriptors vary as
 10 functions of the neutrality of the color indicated by the
 11 first data.

1 15. The computer program product of claim 14
 2 wherein the luminance descriptor varies as a function of a
 3 Y-reference that is a weighted combination of a local white
 4 point Y-value and a common white point Y-value, the Y-
 5 reference being weighted more toward the local white point
 6 Y-value the closer the Y-value of the color indicated by the
 7 first data is to the local white point Y-value and being
 8 weighted more toward the common white point Y-value the more
 9 the Y-value of the color indicated by the first data and the
 10 local white point Y-value differ.

1 16. The computer program product of claim 15
 2 wherein the second data include values for L^* , a^* , and b^* ;
 3 and

4 wherein
 5 $L^* = 116 \times f(Y/Y_n'') - 16$
 6 $Y_n'' = Y_{LW}(1 - \text{sat}(Y, Y_{LW})) + Y_{CW} * \text{sat}(Y, Y_{LW})$
 7 $\text{sat}(Y, Y_{LW}) = 1.0 - (Y/Y_{LW})$
 8 $a^* = 500(f(X/X_n') - f(Y/Y_n'))$
 9 $b^* = 200(f(Y/Y_n') - f(Z/Z_n'))$
 10 $f(\omega) = (\omega)^{1/3} \qquad \omega > 0.008856$

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11       $\hat{f}(\omega) = 7.787(\omega) + 16/116 \quad \omega \leq 0.008856$ 
12       $X_n' = X_{LW}(1 - \text{sat}(C, C_{LW})) + X_{CW} * \text{sat}(C, C_{LW})$ 
13       $Y_n' = Y_{LW}(1 - \text{sat}(C, C_{LW})) + Y_{CW} * \text{sat}(C, C_{LW})$ 
14       $Z_n' = Z_{LW}(1 - \text{sat}(C, C_{LW})) + Z_{CW} * \text{sat}(C, C_{LW})$ 
15       $C = (X, Y, Z)$ 
16       $C_{LW} = (X_{LW}, Y_{LW}, Z_{LW})$ 
17       $\text{sat}(C, C_{LW}) = (\text{dev}X'Y'Z' / \text{maxDev})^\gamma$ 
18       $\text{maxDev} = \text{sqrt}(6.0/9.0) * \max(X', Y', Z')$ 
19       $\text{dev}X'Y'Z' = \text{sqrt}((X' - \text{avg}X'Y'Z')^2 + (Y' - \text{avg}X'Y'Z')^2$ 
20       $\quad + (Z' - \text{avg}X'Y'Z')^2)$ 
21       $\text{avg}X'Y'Z' = (X' + Y' + Z')/3.0$ 
22       $X' = X/X_{LW}$ 
23       $Y' = Y/Y_{LW}$ 
24       $Z' = Z/Z_{LW}$ 
25  where  $C_{LW}$  is a local white vector representing a local white
26  point of the system,  $C_{CW} = (X_{CW}, Y_{CW}, Z_{CW})$  is a common white vector
27  for a common white point of the system, and  $\gamma$  is a variable
28  for scaling the local white vector  $C_{LW}$  relative to the
29  common white vector  $C_{CW}$ .

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1      17. A method of producing a color on a device, the
2  method comprising:
3      obtaining first data associated with a first device
4  and indicative of a first color;
5      determining second data related to stimulus data of
6  the first device by a color appearance model that converts
7  input data to output data using a white reference vector
8  that varies in association with a neutrality of a color
9  indicated by the input data;
10     actuating a second device according to the second
11  data to produce a second color to approximate the first
12  color.

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1 18. The method of claim 17 wherein the white
2 reference vector approaches a white point associated with
3 first device as the color indicated by the input data
4 approaches a neutral color.

1 19. The method of claim 18 wherein the color
2 appearance model includes a luminance descriptor, and a pair
3 of color descriptors that quantify relative amounts of red,
4 green, yellow, and blue in a color indicated by the output
5 data;
6 wherein the luminance descriptor varies as a
7 function of Y, Y being one of tristimulus values X, Y, and Z
8 of the color indicated by the first data; and
9 wherein the pair of color descriptors vary as
10 functions of the neutrality of the color indicated by the
11 first data.

1 20. The method of claim 17 wherein the first data
2 are first device stimulus data of the first device and the
3 second data are second device stimulus data of the second
4 device, and determining the second data comprises mapping
5 third data to fourth data, the third data being converted
6 from the first data using the color appearance model and the
7 fourth data being converted from the second data using the
8 color appearance model.

1 21. A computer program product residing on a
2 computer readable medium, for producing a color on a device,
3 comprising instructions for causing a computer to:
4 obtain first data associated with a first device and
5 indicative of a first color;
6 determine second data related to stimulus data of
7 the first device by a color appearance model that converts

8 input data to output data using a white reference vector
9 that varies in association with a neutrality of a color
10 indicated by the input data;
11 actuate a second device according to the second data
12 to produce a second color to approximate the first color.

1 22. The computer program product of claim 21
2 wherein the white reference vector approaches a white point,
3 associated with each device whose data are used as the input
4 data, as the color indicated by the input data approaches
5 white or a neutral color.

1 23. The computer program product of claim 21
2 wherein the first data are first device stimulus data of the
3 first device and the second data are second device stimulus
4 data of the second device, and the instructions that cause
5 the computer to determine the second data cause the computer
6 to map third data to fourth data, the third data being
7 converted from the first data using the color appearance
8 model and the fourth data being converted from the second
9 data using the color appearance model.

1 24. A method of producing a color with an emissive
2 device using absolute colorimetry, the method comprising:
3 obtaining first data indicative of a first color;
4 determining second data related to the first data by
5 a color appearance model that uses a white point of the
6 emissive device as a white reference vector;
7 actuating the emissive device according to the
8 second data to implement absolute colorimetry to produce a
9 second color to approximate the first color.

1 25. The method of claim 24 wherein the white
2 reference vector varies in association with neutrality of
3 colors to be produced on the emissive device.

1 26. The method of claim 25 wherein the white
2 reference vector varies from the white point of the emissive
3 device when the second color is near white to a common white
4 reference, different from the white point of the emissive
5 device, when the second color departs from a near-white,
6 neutral color.

1 27. A computer program product residing on a
2 computer readable medium, for producing a color with an
3 emissive device using absolute colorimetry, comprising
4 instructions for causing a computer to:
5 obtain first data indicative of a first color;
6 determine second data related to the first data by a
7 color appearance model that uses a white point of the
8 emissive device as a white reference vector;
9 actuate the emissive device according to the second
10 data to implement absolute colorimetry to produce a second
11 color to approximate the first color.

1 28. A method of characterizing an emissive device
2 for absolute colorimetry, the method comprising:
3 obtaining first data indicative of output of the
4 emissive device;
5 converting the first data to second data using a
6 color appearance model that uses a white point of the
7 emissive device as a reference white vector;
8 providing the second data for use in absolute
9 colorimetric color reproduction.

1 29. The method of claim 28 wherein converting the
2 first data to second data further includes using, as the
3 white reference vector, a composite white reference vector
4 that is a weighted combination of the white point of the
5 emissive device and a predetermined white point, the
6 composite white reference vector being closer to the white
7 point of the emissive device the closer a color indicated by
8 the first data is to being neutral.

1 30. ~~A computer program product residing on a~~
2 ~~computer readable medium, for characterizing an emissive~~
3 ~~device for absolute colorimetry, comprising instructions for~~
4 ~~causing a computer to:~~
5 obtain first data indicative of output of the
6 emissive device;
7 convert the first data to second data using a color
8 space that uses a white point of the emissive device as a
9 reference white vector;
10 provide the second data for use in absolute
11 colorimetric color reproduction.

1 31. A method of characterizing colors for
2 reproduction between a first device and a second device, the
3 method comprising:
4 normalizing first tristimulus values indicative of a
5 color of the first device using local black point values;
6 transforming the normalized first tristimulus values
7 to obtain color values indicative of modified cone responses
8 of the human eye;
9 chromatically adapting the color values from a local
10 condition to a reference condition; and
11 transforming the adapted color values to obtain
12 second tristimulus values.

1 32. The method of claim 31 wherein a neutral axis
2 of the local condition is mapped to a neutral axis of the
3 reference condition.

1 33. The method of claim 31 wherein normalizing the
2 first tristimulus values includes dividing by a difference
3 between a local luminance value and a local black point
4 luminance value.

1 34. The method of claim 33 wherein transforming the
2 adapted color values includes multiplying the adapted color
3 values by a reference white point luminance value divided by
4 a difference between a local white point luminance value and
5 the local black point luminance value.

1 35. The method of claim 31 wherein transforming the
2 normalized first tristimulus values is performed using a
3 Bradford transformation.

1 36. The method of claim 35 wherein normalizing the
2 first tristimulus values and transforming the normalized
3 first tristimulus values are performed according to
4
$$\begin{bmatrix} R_1 \\ G_1 \\ B_1 \end{bmatrix} = M_b \begin{bmatrix} (X_1 - X_{1k}) / (Y_1 - Y_{1k}) \\ (Y_1 - Y_{1k}) / (Y_1 - Y_{1k}) \\ (Z_1 - Z_{1k}) / (Y_1 - Y_{1k}) \end{bmatrix}$$

5
6 where $[X_{1k}, Y_{1k}, Z_{1k}]$ is the local black point, X_1 , Y_1 , and Z_1
7 are the first tristimulus values,
8
$$\begin{bmatrix} 0.8951 & 0.2664 & -0.1614 \end{bmatrix}$$

9
$$M_b = \begin{bmatrix} -0.7502 & 1.7135 & 0.0367 \\ 0.0389 & -0.0685 & 1.0296 \end{bmatrix}$$
, and
10
11 R_1 , G_1 , and B_1 are the color values indicative of modified
12 cone responses of the human eye.
13

1 37. The method of claim 36 wherein chromatically
2 adapting the color values is performed according to

$$\begin{aligned} 3 \quad R_{\text{ref}} &= (R_{\text{rw}}/R_{\text{lw}}) \times R_1 \\ 4 \quad G_{\text{ref}} &= (G_{\text{rw}}/G_{\text{lw}}) \times G_1 \\ 5 \quad B_{\text{ref}} &= \text{Sign}[B_1] \times (B_{\text{rw}}/B_{\text{lw}}^\beta) \times |B_1|^3 \\ 6 \quad \beta &= (B_{\text{lw}}/B_{\text{rw}})^{0.0834} \end{aligned}$$

7 where R_{rw} , G_{rw} , and B_{rw} are RGB values of a reference white
8 point, R_{lw} , G_{lw} , and B_{lw} are RGB values of a local white
9 point.

1 38. The method of claim 37 wherein transforming the
2 adapted color values to second tristimulus values is
3 performed according to

$$\begin{aligned} 4 \quad \begin{bmatrix} X_{\text{ref}} \\ Y_{\text{ref}} \\ Z_{\text{ref}} \end{bmatrix} &= M_b^{-1} \begin{bmatrix} R_{\text{ref}} \times Y_1 \times Y_{\text{rw}} / (Y_{\text{lw}} - Y_{\text{lk}}) \\ G_{\text{ref}} \times Y_1 \times Y_{\text{rw}} / (Y_{\text{lw}} - Y_{\text{lk}}) \\ B_{\text{ref}} \times Y_1 \times Y_{\text{rw}} / (Y_{\text{lw}} - Y_{\text{lk}}) \end{bmatrix} \end{aligned}$$

1 39. The method of claim 31 wherein transforming the
2 normalized first tristimulus values is performed using a von
3 Kries transformation.

1 40. The method of claim 39 wherein

$$\begin{aligned} 2 \quad \begin{bmatrix} X_{\text{ref}} \\ Y_{\text{ref}} \\ Z_{\text{ref}} \end{bmatrix} &= M_v^{-1} \begin{bmatrix} L_{\text{rw}} & 0 & 0 \\ 0 & M_{\text{rw}} & 0 \\ 0 & 0 & S_{\text{rw}} \end{bmatrix} \begin{bmatrix} 1/(L_{\text{lw}}-L_{\text{lk}}) & 0 & 0 \\ 0 & 1/(M_{\text{lw}}-M_{\text{lk}}) & 0 \\ 0 & 0 & 1/(S_{\text{lw}}-S_{\text{lk}}) \end{bmatrix} \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} \\ 3 \quad & \\ 4 \quad & \end{aligned}$$

5 where

$$\begin{aligned} 6 \quad & \begin{bmatrix} 0.38791 & 0.68898 & -0.07868 \end{bmatrix} \\ 7 \quad M_v &= \begin{bmatrix} -0.22981 & 1.18340 & 0.04641 \end{bmatrix} \\ 8 \quad & \begin{bmatrix} 0 & 0 & 1.0 \end{bmatrix} \end{aligned}$$

9 and where $[L_{rw}, M_{rw}, S_{rw}]$ are LMS (long, medium, and short
10 wavelength band) values of the reference white, $[L_{lw}, M_{lw},$
11 $S_{lw}]$ are LMS values for local white, $[L_{lk}, M_{lk}, S_{lk}]$ are LMS
12 values for local black, $X_1, Y_1,$ and Z_1 are the first
13 tristimulus values, and $X_{ref}, Y_{ref},$ and Z_{ref} are the second
14 tristimulus values.

1 41. The method of claim 31 wherein the first device
2 is a print device and the second device is a print device,
3 tristimulus values of a common illuminant are used as
4 reference tristimulus white values for both print devices,
5 media white tristimulus values of each print device are used
6 as local tristimulus white values for both print devices,
7 and Bradford-type adaptations are used for both print
8 devices to implement media-relative colorimetry.

1 42. The method of claim 31 wherein the first device
2 is a print device and the second device is a display device,
3 tristimulus values of a reference illuminant are used as
4 reference tristimulus white values, media white tristimulus
5 values of the print device are used as local tristimulus
6 white values for the print device, monitor white tristimulus
7 values of the display device are used as local tristimulus
8 values for the display device, and Bradford-type adaptations
9 are used for both the first and second devices to implement
10 media-relative colorimetry.

1 43. The method of claim 31 wherein the first device
2 is a print device and the second device is a display device,
3 tristimulus values of a reference illuminant are used as
4 reference tristimulus white values, media white tristimulus
5 values of the print device are used as local tristimulus
6 white values, monitor white tristimulus values of the

7 display device are used as local tristimulus values for the
8 display device, Bradford-type adaptation is used for the
9 display device, and absolute CIE-Lab is used for the print
10 device to implement absolute colorimetry.